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Hidden Supersymmetry.

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Abstract

Using the concept of complementarity, we present a model for the weak interactions with unbroken gauge symmetry and unbroken supersymmetry. The observable particles are bound states of some more fundamental particles. Supersymmetry is broken at the macroscopic scale of the observable particles by a discrete symmetry but remains exact at the scale of the fundamental particle and is thus hidden. This provides a link between theories at very high energies and the observed particle physics. Supersymmetric particles are confined in usual matter.

1 Introduction

't Hooft in seminal papers [1, 2] has shown that in a gauge theory with a Higgs boson in the fundamental representation of the gauge group there is no fundamental difference between the theory in the Higgs phase, i.e, with a gauge symmetry broken by means of the Higgs mechanism and the theory in the confinement phase i.e, a theory with confined gauge charges. This property is known as the complementarity principle [3]. The fundamental difference between the electroweak theory and QCD is then that in the electroweak sector, one has a large parameter which allows perturbative calculations.

Recently we have used this complementarity to build an alternative to the standard model using a $SU(2)_L \otimes U(1)_Y$ gauge group with $SU(2)_L$ confinement [4]. We have clarified how to incorporate quantum electrodynamics in that kind of models and studied the physical consequences of the assumption that the electroweak interactions might be described by the confinement phase. In that case all phenomena in particle physics are described by exact gauge theories. If nature is such that its fundamental Lagrangian has the maximal number of allowed symmetries, it is natural to assume that supersymmetry could also be an exact symmetry of this Lagrangian. Supersymmetry is a crucial aspect in particle physics, it is a desirable feature of many high energy theories like superstring theories or grand unified theories. Unfortunately supersymmetry has not yet been discovered. It is the missing link between very high energy physics and low energy particle physics.

It is thus meaningful to design mechanisms that explain why supersymmetry is unobserved. A possibility is that supersymmetry is broken. This leads to models such as the minimal supersymmetric standard model. But, such models predict a light Higgs boson which if not discovered soon would rule them out. We propose an alternative point of view. If the electroweak interactions are described by the confinement phase, the microscopic theory can be supersymmetric but this symmetry is then hidden at the macroscopic scale of fermions and electroweak bosons. In other words we will break supersymmetry at the macroscopic scale without breaking it at the scale of fundamental particles thus providing a link between very high energy physics and low energy particle physics.

2 A supersymmetric theory

We shall consider a toy model with the gauge group $SU(2)_L$ and unbroken $N = 1$ supersymmetry. We assume that there is a $SU(2)_L$ confinement: all physical particles are $SU(2)_L$ singlets. We have the following particle spectrum: the right-handed fermions e_R, u_R, d_R and their superpartners $\tilde{e}_R$, $\tilde{u}_R$, $\tilde{d}_R$. The right-handed particles are the usual right-handed leptons and quarks of the standard model and their superpartners, whereas the left-handed doublets are bound states of some more elementary particles. The fundamental $SU(2)_L$ fields (D-quarks) are:

leptonic D-quarks $\quad l_i = \begin{pmatrix} l_1 \\ l_2 \end{pmatrix} \quad$ (fermions)

hadronic D-quarks $\quad q_i = \begin{pmatrix} q_1 \\ q_2 \end{pmatrix} \quad$ (fermions, $SU(3)_c$ triplets)

scalar D-quarks $\quad h_i = \begin{pmatrix} h_1 \\ h_2 \end{pmatrix} \quad$ (bosons).

Notice that in order to cancel the anomalies we would have to introduce a second scalar doublet. We discard this problem as our aim is only to present a toy model to emphasize our idea. We then have the superpartners

leptonic D-squarks $\quad \tilde{l}_i = \begin{pmatrix} \tilde{l}_1 \\ \tilde{l}_2 \end{pmatrix} \quad$ (bosons)

hadronic D-squarks $\quad \tilde{q}_i = \begin{pmatrix} \tilde{q}_1 \\ \tilde{q}_2 \end{pmatrix} \quad$ (bosons, $SU(3)_c$ triplets)

scalar D-squarks $\quad \tilde{h}_i = \begin{pmatrix} \tilde{h}_1 \\ \tilde{h}_2 \end{pmatrix} \quad$ (fermions).

We shall refer to the theory involving the D-quarks and the D-squarks as the microscopic theory. At the macroscopic level i.e, the theory of bound states, a large number of $SU(2)_L$ invariant bound states can be identified. We see that bound states of different particles can have the same quantum numbers. For example, the neutrino can be identify with the bound state $\bar{h}l$ but also with the bound state $\bar{\tilde{h}}\tilde{l}$. It will thus be a superposition of both bound states. This can be applied to the rest of the known particles. The left-handed fermions, normalized in the appropriate way, are defined as follows.

We have the leptons

$$\text{left-handed neutrino } \nu_L = \frac{1}{F}\left((\bar{h}l) + (\bar{\tilde{h}}\tilde{l})\right) \tag{1}$$
$$\text{left-handed electron } e_L = \frac{1}{F}\left((\epsilon^{ij}h_i l_j) + (\epsilon^{ij}\tilde{h}_i\tilde{l}_j)\right)$$

where F is a numerical, to be specified, normalization factor. The quarks are also bound states

$$\text{left-handed up quark } u_L = \frac{1}{F}\left((\bar{h}q) + (\bar{\tilde{h}}\tilde{q})\right) \tag{2}$$
$$\text{left-handed down quark } d_L = \frac{1}{F}\left((\epsilon^{ij}h_i q_j) + (\epsilon^{ij}\tilde{h}_i\tilde{q}_j)\right).$$

The Higgs and electroweak bosons are bound states of scalar D-quarks and their superpartners:

$$\text{Higgs field } \phi = \frac{1}{2F}\left((\bar{h}h) + \beta(\bar{\tilde{h}}\tilde{h})\right) \tag{3}$$
$$\text{electroweak boson } W^3_\mu = \frac{2i}{gF^2}\left((\bar{h}D_\mu h) + \beta(\bar{\tilde{h}}D_\mu\tilde{h})\right)$$
$$\text{electroweak boson } W^-_\mu = \frac{\sqrt{2}i}{gF^2}\left((\epsilon^{ij}h_i D_\mu h_j) + \beta(\epsilon^{ij}\tilde{h}_i D_\mu\tilde{h}_j)\right),$$

where D_μ is the covariant derivative of the gauge group $SU(2)_L$ involving the gauge bosons B^a_μ and g is the gauge coupling of this group. The second charged W boson W^+ is defined as $(W^-)^\dagger$. A simple dimensional analysis shows that a constant β with dimension -1 has to appear. This constant is a priori unknown but the only scale of the theory being F, we could impose $\beta = 1/F$. This apparently arbitrary choice is not a drawback for the theory as we will see that only the terms containing a scalar D-quark doublet will be relevant. We see that if we perform a supersymmetric transformation on one of the left-handed field we obtain, up to some irrelevant factors, the corresponding superpartner at least as far as the quantum numbers are concerned.

The problem is to know whether a particle and its superparticle will belong to the same supermultiplet, i.e, if they have the same mass. It is a difficult question as dynamical effects can contribute to the masses. For example, the masses of the electroweak bosons are definitely of dynamical origin. There are two possibilities: either the masses of, for example, an electroweak boson and of the corresponding superparticle are identical, supersymmetry is unbroken at the macroscopic level or they are different because of dynamical effects and supersymmetry is dynamically broken. In the sequel we assume that these particles indeed form a supermultiplet. Thus, an electron is the superpartner of a selectron.

All the particles we have identified up to this point are those appearing in the standard model. We can also identify the bounds states corresponding to the macroscopic superparticles. For example, we have

$$\text{selectron } \tilde{e} = \frac{1}{F}\left((\epsilon^{ij} h_i \tilde{l}_j) + \beta(\epsilon^{ij} \tilde{h}_i l_j)\right)$$

for the left-handed selectron. But, we then have to assume that some dynamical mechanism breaks supersymmetry at the macroscopic level. We prefer to introduce a mechanism very similar to the so-called R-parity. We assign a new quantum number to the particles. We call this new quantum number R-parity too. The D-quarks are assigned an even R-parity, whereas the D-squarks are assigned an odd R-parity. We then assume that the bound states appearing in nature have an even R-parity. In other words we break supersymmetry at the macroscopic level by imposing a discrete symmetry but it remains intact at the microscopic level. It is thus clear that superparticles corresponding to the left-handed particles, to the Higgs sector and to the electroweak bosons will not be observable. In that case the complementarity breaks down and we expect the confinement phase to describe nature correctly. The fundamental D-squarks are confined in usual matter.

Even if supersymmetry was broken by dynamical effects, it might still be necessary, if the mass splitting was not sufficiently large, to introduce the R-parity for phenomenological reasons.

3 Back to known particles

It remains to show that the definitions for the fields indeed describe the observed particles. We use the unitary gauge for the scalar doublet

$$h_i = \begin{pmatrix} F + h_{(1)} \\ 0 \end{pmatrix}. \tag{4}$$

The parameter F is a real number. If F is sufficiently large we can perform a $1/F$ expansion for the fields defined previously, we then have

$$\begin{aligned}
\nu_L &= l_1 + \frac{1}{F}\left(h_{(1)}l_1 + \bar{\tilde{h}}\tilde{l}\right) \approx l_1 \\
e_L &= l_2 + \frac{1}{F}\left(h_{(1)}l_2 + \epsilon^{ij}\tilde{h}_i\tilde{l}_j\right) \approx l_2 \\
u_L &= q_1 + \frac{1}{F}\left(h_{(1)}q_1 + \bar{\tilde{h}}\tilde{q}\right) \approx q_1 \\
d_L &= q_2 + \frac{1}{F}\left(h_{(1)}q_2 + \epsilon^{ij}\tilde{h}_i\tilde{q}_j\right) \approx q_2 \\
\phi &= h_{(1)} + \frac{F}{2} + \frac{1}{2F}\left(h_{(1)}h_{(1)} + \beta\bar{\tilde{h}}\tilde{h}\right) \approx h_{(1)} + \frac{F}{2} \\
W_\mu^3 &= \left(1 + \frac{h_{(1)}}{F}\right)^2 B_\mu^3 + \frac{2i}{gF}\left(1 + \frac{h_{(1)}}{F}\right)\partial_\mu h_{(1)} \\
&\quad + \frac{2i\beta}{gF^2}\left(\bar{\tilde{h}}D_\mu\tilde{h}\right) \approx B_\mu^3 \\
W_\mu^- &= \left(1 + \frac{h_{(1)}}{F}\right)^2 B_\mu^- + \frac{\sqrt{2}i\beta}{gF^2}\left(\epsilon^{ij}\tilde{h}_i D_\mu\tilde{h}_j\right) \approx B_\mu^- .
\end{aligned} \tag{5}$$

As also done by ’t Hooft [1, 2], we assume that the only particles which are stable enough to be observable at presently accessible energies are those containing the scalar doublet h, those are the only fields who survive to the expansion, and we consider the terms suppressed by a factor $1/F$ as being irrelevant. Therefore the spectrum of this theory is, for the left-handed sector, identical to the spectrum of the standard model. Nevertheless we are not able to hide the superpartners of the right-handed particles at this stage. Supersymmetry is apparently broken in the left-handed sector but in fact it remains unbroken at the microscopic level of the theory.

4 Conclusions

We have considered a toy model with $SU(2)_L$ confinement and hidden supersymmetry in the left-handed sector. Supersymmetry is broken at the macroscopic level by a discrete symmetry. The first step towards a realistic model is to include a second Higgs doublet. It can be done without major difficulties [5]. This has not been done here in order to keep the formalism as simple as possible. The asymptotic behavior of our model then depends on the way one extends the model to three families. If we add two more doublets to the theory and the corresponding superpartners, the beta function is positive. Thus if at some low energy the theory is confined, it remains confined in the very high energy limit. We have a permanent confinement. This is not a disaster since we assume that the $SU(2)$ gauge group will be absorbed into a larger gauge group at a finite unification scale. If we interpret the remaining families as excited versions of the first family, i.e. we have a single fundamental doublet, then the beta function is negative and the theory is asymptotic free.

This model can be extend to a theory with a $SU(3)_c \otimes SU(2)_R \otimes SU(2)_L \otimes U(1)_Y$ gauge group with two Higgs doublets for each $SU(2)$ sector. Once this extension has been done, we can hide supersymmetry completely at the microscopic level for the $SU(2)_R \otimes SU(2)_L$ sector, assuming a $SU(2)_R \otimes SU(2)_L$ confinement. Supersymmetry would have to be broken by usual means for the two remaining gauge groups. The spectrum of the macroscopic theory is then that of the standard model with ten Higgs fields, i.e. five for each $SU(2)$ sector, 8 gluinos and a photino.

This theory provides the missing link between low energy particle physics and very high energy theories like superstring theories or cosmology. Usual models with supersymmetry breaking are not able to explain a small cosmological constant [6]. In our approach, supersymmetry is not broken in the $SU(2)_R \otimes SU(2)_L$ sector but is only hidden. Thus the contribution of the energy of the fundamental vacuum of that sector to the cosmological constant is vanishing. Our mechanism can therefore help to explain a small or vanishing cosmological constant.

Note that this model would nicely fit into a supersymmetric $SO(10)$ grand unified theory, which thus could be the fundamental theory of D-quarks and D-squarks. The fundamental theory could be locally supersymmetric and thus include quantum gravity. It turns out that such a theory would be very similar to the standard model if there is a confinement in the weak interactions sector.

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